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ABSTRACT

This paper reports on three studies concerned with aspects of human visual information processing. Study I was an effort to measure the duration of iconic storage using a partial report method in children ranging in age from 6 to 13 years. Study II was designed to detect age related changes in the rate of processing (perceptually encoding) letters from iconic storage into more permanent memory. Subjects were 2nd- and 5th-grade children and undergraduates. Study III measured memory and scanning rates in children and adults using letters of the alphabet as memory items. A number of results are discussed. (MS)

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AGE AND VISUAL INFORMATION PROCESSING[1]

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(Presented at the Sixteenth Annual Meeting of the Psychonomic Society in Denver, Colorado, November 7, 1975)

As part of an ongoing program, we have conducted three developmental studies in the past year, each concerned with a different aspect of human visual information processing.

Study I was an effort to measure the duration of iconic storage using a partial report method, in children ranging in age from six to thirteen years. A number of findings in several areas (Brown, 1965; Gummerman & Gray, 1972; Liss & Haith, 1970; Pollack, 1965; Pollack, Ptashne, & Carter, 1969; Spitz & Thor, 1968; Spitz & Webreck, 1971; Thor, 1970; Thor & Thor, 1970; Welsandt & Meyer, 1974; Welsandt, Zupnick, & Meyer, 1973) have indicated that icon duration might be negatively correlated with age. Such a finding would be helpful for interpretations of data from developmental studies using brief unmasked stimuli, so we felt it important to test the idea directly.

Study II was designed to detect age-related changes in the rate of processing (perceptually encoding) letters from iconic storage into more permanent memory. Children and adults viewed displays of either two or four randomly selected consonants for various brief durations, always with a pattern mask immediately following the stimuli, and we addressed the questions of parallel vs. serial processing of the letters and the rates of processing.

PS 009392

Study III was motivated in part by recent studies that found, surprisingly, no developmental differences in memory scanning rates (Sternberg, 1966, 1975) using line drawings (Hoving, Morin, & Konick, 1970), digits (Harris & Fleer, 1974), and Gibson forms (Silverman, 1974) as stimuli. We also measured memory scanning rates in children and adults, but in our case the target and memory items were letters.

Study I: Icon Duration

Our approach to this problem was to obtain a sample of children whose ages were fairly evenly distributed over the range of interest, to run each of them extensively to obtain individual "icon-decay" curves, to estimate icon durations from those curves, and to correlate the estimated values with the children's ages. The method for producing the icon-decay curves was a version of the partial report procedure introduced by Sperling (1960) and modified by Keele and Chase (1967), which Sheingold (1973) and Morrison, Holmes, and Haith (1974) have previously used in developmental studies with different purposes from ours.

Our subjects were thirteen boys, aged 6.08 to 12.92 years, enrolled in a summer day camp.[2] They participated in a practice session and from three to seven testing sessions depending on their availability (nine served in seven sessions, one in five, one in four, and two in three). All conditions of the experiment were run in every session.

The stimuli were viewed monocularly in a three-field Scientific Prototype automated tachistoscope. The background was always white, and its luminance was 82 cd/m^2. Each of the 56 stimuli consisted of ten

black solid geometric forms (square, circle, triangle, star, and X, each reproduced twice) that subtended 0.36 deg. visual angle each; the ten forms were arrayed in random sequence (different for each stimulus) on the circumference of a 2.33 deg. diameter imaginary circle surrounding a central fixation point. On every trial, a cue (a bar 0.56 deg. in length) appeared at the center of the field, extending from the fixation point toward the location of the one form that was to be reported. The stimulus and cue durations were 50 and 75 msec., respectively; the cue followed the stimulus offset at ISIs of 0, 100, 300, 600, 1000, 1500, and 3000 msec. The ISIs were varied across seven blocks of eight trials each in pseudo-random orders that were counterbalanced over seven sessions. The form cued and the location cued were selected unsystematically with the constraint that each form and location be cued about the same number of times each session.

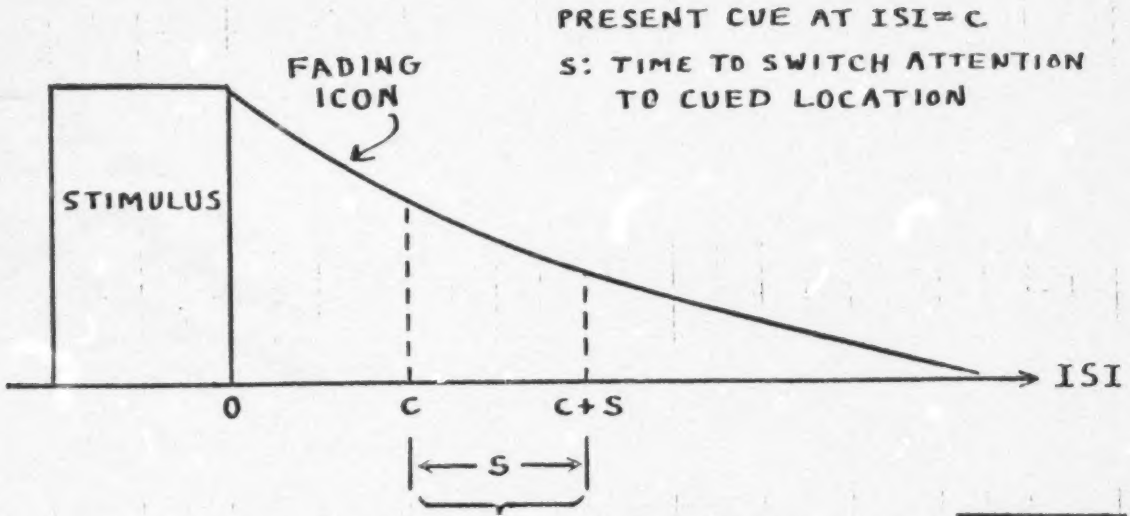
Each subject's identification accuracy was plotted as a function of ISI. Three judges--who were only generally familiar with the purpose of the study and who had no knowledge of the identities or ages of the subjects run--independently viewed copies of the plots and estimated by eye the smallest ISI value at which performance reached the low asymptotic level defined by the largest ISIs. These "minimum asymptotic ISI" values, or MAIs, which we felt would reflect icon duration, were estimated consistently by the judges: The inter-judge correlations were +0.80, +0.70, and +0.76. The three estimated MAIs for each subject were averaged to produce a single score.

The average MAI values, when related to the subjects' ages, produced an unexpected correlation coefficient, +0.57, which was

significantly greater than zero. The least squares regression equation relating the variables was MAI = 218.5 + 59.9(Age), apparently indicating that icon duration increased, not decreased, by 60 msec. per year.

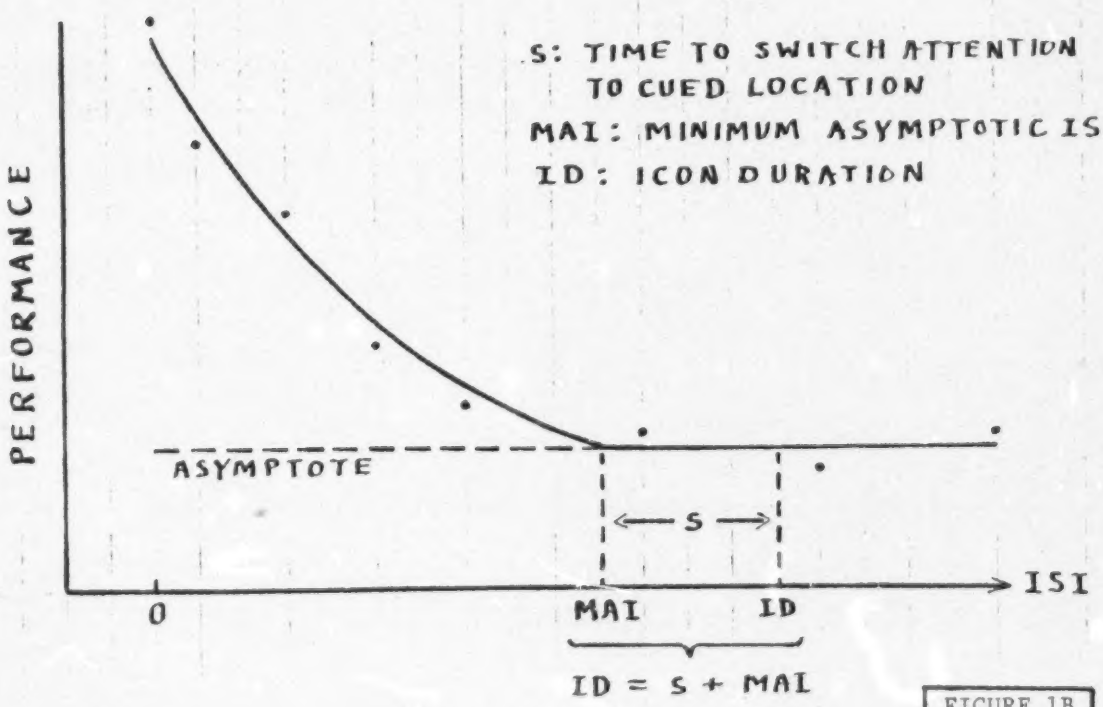
However, we were, and we remain, unwilling to accept the idea that icon duration increases with age. To explain the finding, we considered a factor that is in fact confounded with icon duration in experiments of this type--the time required to switch attention to the location cued by the bar marker. As Figure 1A indicates, the existence of a nonzero switching time (s) implies that subjects cannot process the cued stimulus item at the moment the cue is presented (ISI=c); rather, their processing when ISI=c is based on the state of the icon at time c+s. Since there are indications that s is on the order of 200 msec. in adults (Averbach & Coriell, 1961; Eriksen & Collins, 1969), performance at any given ISI actually reflects a considerably "older" icon. Figure 1B represents the general form of our data and the procedure we used to estimate MAI. Clearly, MAI does not directly give the duration of the icon, ID, but underestimates ID by the value of s. That is, ID = s + MAI.

It follows that changes in these variables from year i to year i+1 (denoted by Δ) are related in similar fashion, $\Delta ID = \Delta s + \Delta MAI$. For our study, $\Delta ID = \Delta s + 60$. Therefore, with no estimate of s available to us, we cannot isolate the value of ΔID. As a result, our finding that MAI increases 60 msec. per year is in fact consistent with two interpretations: Either (a) ID remains constant over age ($\Delta ID = 0$) and s decreases by 60 msec. per year ($\Delta s = -60$), or (b) both ID and s decrease with age, with s decreasing by 60 msec. more per year than



WITH CUE AT ISI = C, PERFORMANCE IS BASED ON ICON AT ISI = C+S

FIGURE 1A



ID = S + MAI

FIGURE 1B

ID ($\Delta ID = -k$; $\Delta s = -k-60$). Logically, there are other possibilities, but they are ruled out by our belief that ΔID and Δs cannot take on positive values.

Study I, then, has not told us what we wanted to know about icon duration. But we have learned that switching time decreases significantly as children mature, so developmental studies using the partial report method to estimate icon duration must be supplemented by a method to estimate the switching time as well.

Study II: Encoding Rate

This project was a developmental extension of the processing rate paradigm popularized by Sperling (1963, 1967) and used in modified form by Haber, Standing, and Boss (cited in Haber, 1973). Horizontal arrays of letters were exposed briefly, and a visual pattern mask always appeared immediately after the letters' offset to make their persisting icon unavailable for further processing. The number of letters named, when related to the letters' exposure duration, provided a measure of the rate of extracting information from the icon. Sperling found that performance was more or less linearly related to exposure duration and was essentially unaffected by the number of letters in the array--results which are consistent with a serial encoding model (Sperling, 1963; Neisser, 1967), though not really sufficient to rule out all models of parallel encoding (Sperling, 1967; Haber, 1973).

The subjects--twenty second-graders, twenty fifth-graders,[3] and twenty University of Texas undergraduates--each served in two sessions

(the first for practice only). They viewed both 2-letter and 4-letter displays at five exposure durations.

The apparatus was the same as in Study I. The stimuli were randomly selected consonants centered in the viewing area and typed (IBM Prestige Elite 72) in horizontal linear arrays with a single typewriter space between each consonant. Each letter was 0.52 deg. tall and about 0.42 deg. wide. The 2-letter array spanned 1.48 deg.; the 4-letter array, 3.63 deg. The pattern mask subtended 4.60 deg. horizontally and 2.43 deg. vertically; it consisted of three rows of the symbol ▣ repeated without spacing, the middle row directly superimposed on the stimulus line and a row immediately above and below. The mask duration was 250 msec. All backgrounds were white (luminance, 86 cd/m^2); pre-stimulus and post-mask fields were equally bright and contained a central fixation point.

In the test session, 120 different stimuli were viewed by each subject: twelve 2-letter displays and twelve 4-letter displays at each of five exposure durations. The set of exposure durations, determined in pilot work, differed for each age and display size in order to minimize the amount of responding at "floor" and "ceiling" levels. For second-graders, the durations were 15, 30, 45, 60, and 75 msec. for 2-letter displays and 15, 40, 65, 90, and 115 msec. for 4-letter displays. For fifth-graders, they were 15, 25, 35, 45, and 55 msec. for two letters and 15, 35, 55, 75, and 95 msec. for four letters. For adults, they were 15, 25, 35, 45, and 55 msec. for two letters and 15, 30, 45, 60, and 75 msec. for four letters. For each subject, all the data from one display size were collected before moving to the other

display size; display size order was counterbalanced over subjects. The order of presenting blocks at the various exposure durations was pseudo-random and counterbalanced over subjects. For 2-letter displays, subjects were required to respond vocally with the names of two letters; for 4-letter displays, with four letters. For the data reported here, the responses were not required to be in correct order. The scores were corrected for guessing.

Figure 2 shows the outcome. For adults, performance with 4-letter displays (N=4) was markedly superior to performance with 2-letter displays (N=2). For fifth-graders, however, N=4 performance was essentially equivalent to N=2 performance; and the second-graders' data showed a reversal--N=4 was inferior to N=2.

The fifth-graders' data do seem to be compatible with a serial processing model, and the second-graders' data can be accommodated by that model as well if we assume that their N=4 scores were depressed somehow--perhaps because four items are above their immediate memory span (Boswell, Sanders, & Young, 1974; Haith, Morrison, Sheingold, & Mindes, 1970). The adult data, however, can be explained only in terms of parallel processing of the items; and, as we will suggest, it is also possible to extend the parallel processing interpretation to the children's data.

Figures 3 and 4 outline a simple view of a parallel processing model that can account for the adult data. (In these Figures, display sizes N=1, 2, and 4 are considered.) Figure 3, an unlimited-capacity model, indicates that the amount of time required to process (identify) an item varies from trial to trial so that a distribution of processing

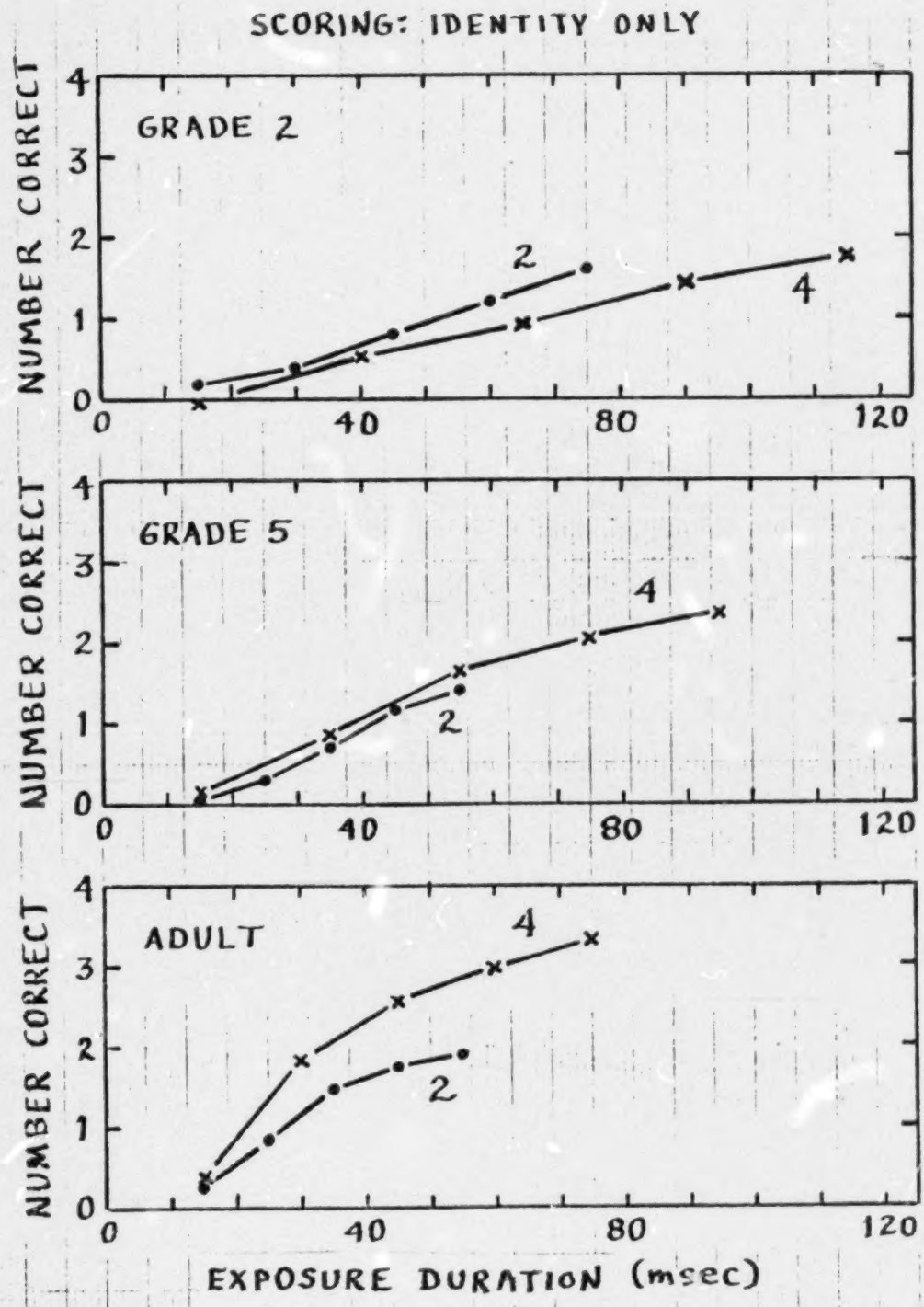
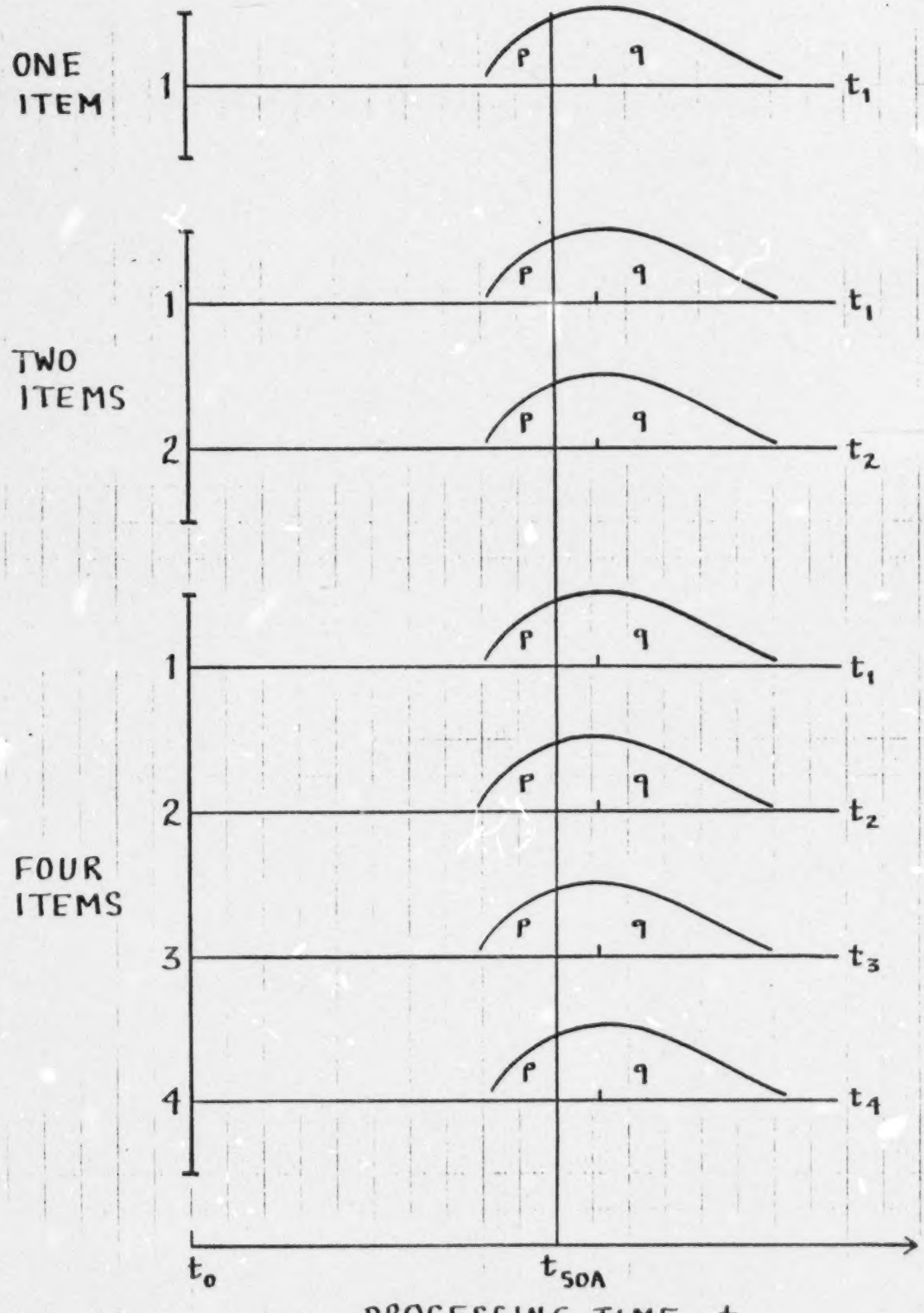

SCORING: IDENTITY ONLY
GRADE 2
GRADE 5
ADULT
NUMBER CORRECT
NUMBER CORRECT
NUMBER CORRECT
0
1
2
3
4
0
40
80
120
2
4
EXPOSURE DURATION (msec)

FIGURE 2


ONE ITEM
TWO ITEMS
FOUR ITEMS
1
2
3
4
P
q
t_1
t_2
t_3
t_4
t_0
t_{SOA}
PROCESSING TIME, t

11 FIGURE 3

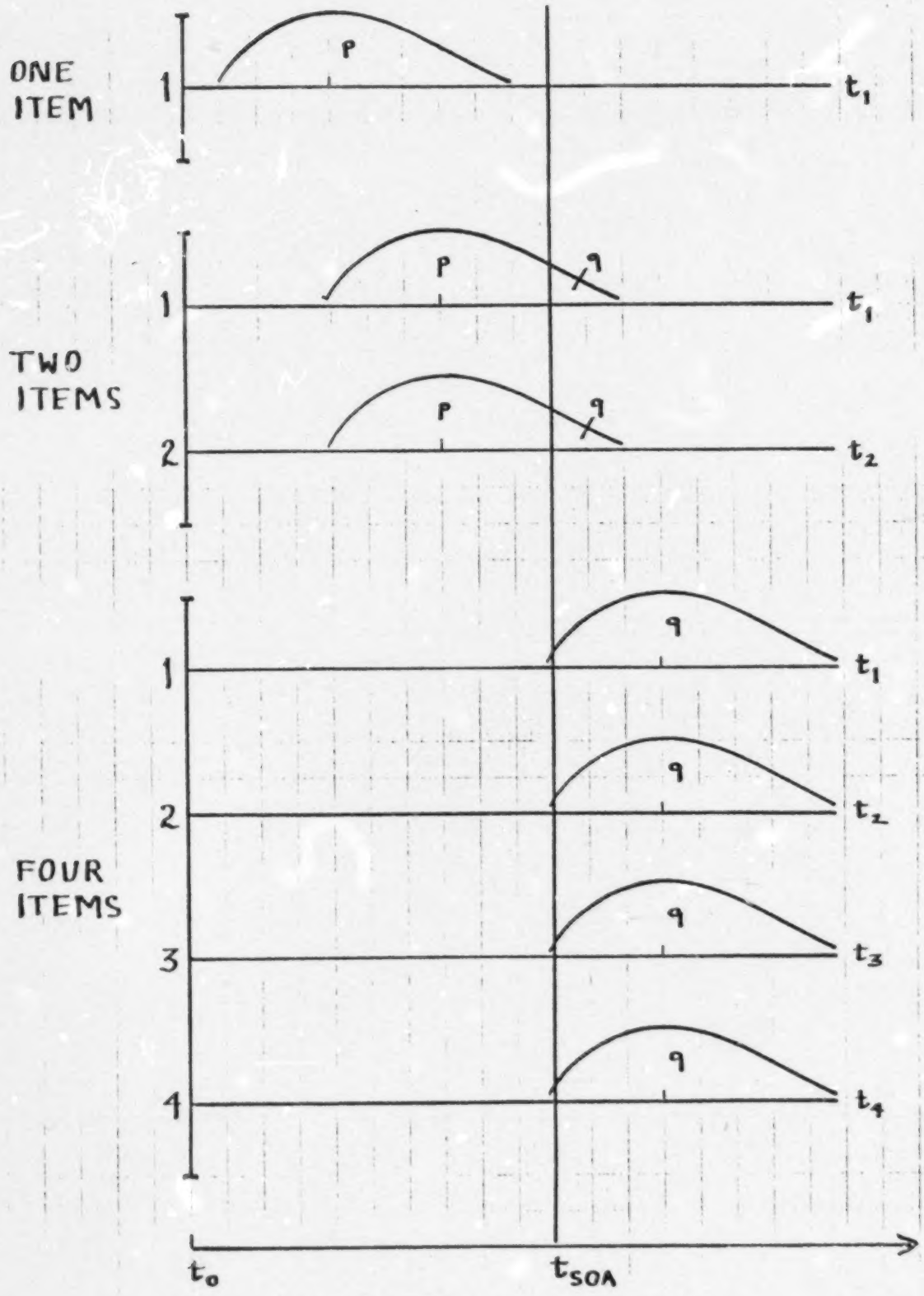

ONE ITEM
1
p
t_1
TWO ITEMS
1
p
q
t_1
2
p
q
t_2
FOUR ITEMS
1
q
t_1
2
q
t_2
3
q
t_3
4
q
t_4
t_0
t_{SOA}
PROCESSING TIME, t

FIGURE 4

times is built up over the course of an experiment. Furthermore, the shape and mean of the distribution is the same for each of the items[4] and is also unaffected by the number of items being processed (the unlimited-capacity feature). Presenting a masking pattern at time t_{SOA} has the following effect. On some proportion of trials (p), processing will be completed before t_{SOA}, so the item(s) will be correctly named; on the remaining trials (q), the item(s) will not be identified. Considering the identification/nonidentification outcome for each of the N items to be a Bernoulli trial, it follows that the expected number of items correctly named at t_{SOA} is given simply by Np. That is, at any given exposure duration (t_{SOA}), performance for N=4 will be double that for N=2. The adults' performance (Figure 2) is not greatly discrepant from this prediction.

Figure 4 is an example of what may happen if processing capacity is limited. The speed of making each identification is reduced by a factor related to N, so that the processing-time distributions are shifted farther to the right as N increases. At any single exposure duration, therefore, p is reduced as N increases, and performance (Np) is reduced accordingly.

Following this limited-capacity parallel processing model, and by appropriately choosing the factor that reduces processing speed as N increases, we can predict that performance with N=4 will be either (a) slightly less than twice as good as N=2 performance, (b) equal to N=2 performance, or (c) poorer than N=2 performance. Referring again to the results of the study (Figure 2), it is clear that these predictions correspond, respectively, to the data of the adults (a),

fifth-graders (b), and second-graders (c).

Thus, the performance of all subjects is compatible with a limited-capacity parallel processing model in which the magnitude of the limitation is inversely related to age. This is a conclusion quite similar to that reached recently by Blake (1974) in a study very much like the present one.

There is an additional aspect of the data that lends support to such a view. Figure 5 gives the accuracy of reporting each location in the displays as a function of exposure duration. The pattern is similar for all age groups. For 2-letter displays, there is equivalent performance at both locations; for 4-letter displays, accuracy at location n+1 shows marked improvement with increasing exposure duration well before location n is reported with great accuracy. This finding is equivalent to Sperling's (1967) and Haber, Standing, and Boss' (Haber, 1973) and is easily explained in terms of parallel processing. While it is also possible to devise variations on serial models to explain the finding,[5] it would be inappropriate for the adults: Recall that their data shown in Figure 2 are compatible with parallel processing only. Since the children's data in Figure 5 are so much like the adults', it seems most reasonable to explain theirs in terms of parallel processing also.

One final analysis is of interest. Following the parallel model, we can use Figure 2 to estimate the medians of the processing-time distributions of Figure 4. When exposure duration (t_{SOA} of mask) is set at the median of the distributions for any display size, then p=0.5 and performance will be equal simply to 0.5N. Reading from

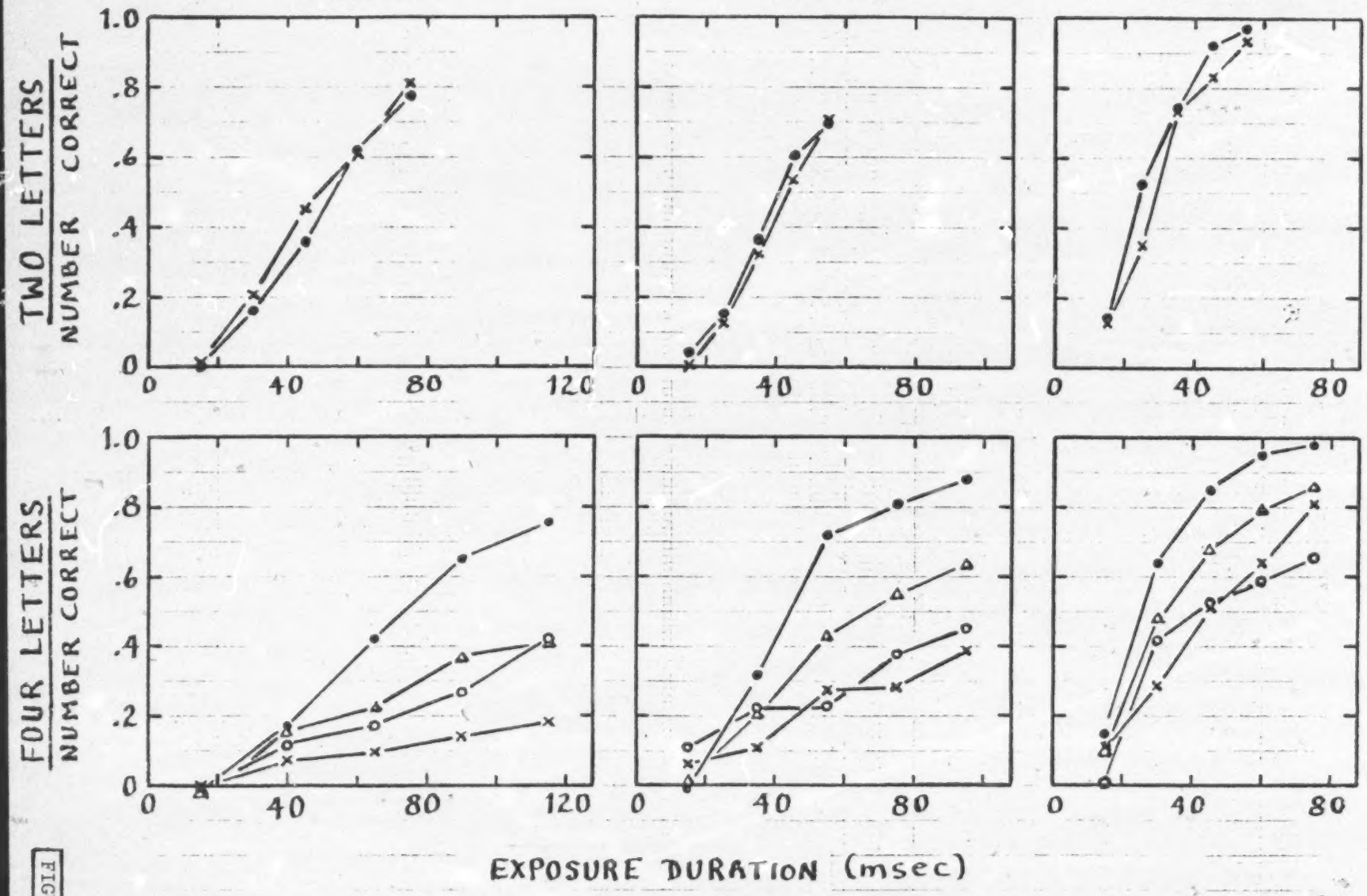

GRADE 2
GRADE 5
ADULT
TWO LETTERS
NUMBER CORRECT
FOUR LETTERS
NUMBER CORRECT
1.0
.8
.6
.4
.2
0
0
40
80
120
EXPOSURE DURATION (msec)
SCORING: IDENTITY ONLY
POSITIONS: •1 ×2 ○3 △4

FIGURE 5

Figure 2 the exposure durations that produce this level of performance for each value of N and each age, the estimated values of median processing time per item are shown in Figure 6. (The second-graders' value at N=4 was obtained by extrapolation.) This strong interaction between age and display size reflects clearly the retardation of children's processing speed produced by increasing display size.

Study III: Memory Scanning Rate

In view of the indications from Studies I and II (as well as from other sources) that some aspects of young children's perceptual processing are relatively show, we were puzzled by the reports that memory scanning rates (Sternberg, 1966) are equivalent in children and adults (Harris & Fleer, 1974; Hoving, Morin, & Konick, 1970; Silverman, 1974). Since Cavanagh (1972) noted that the scanning rates obtained in adult studies are partly dependent on the class of stimuli used, we decided to conduct a developmental study using letters, a class not previously explored with children.

The subjects were twelve first-graders, twelve fourth-graders,[6] and twelve University of Texas undergraduates; each served in a practice session and one testing session. The stimuli were the 26 capital letters of the alphabet, constructed from black 48-pt. Futura Bold Chartpak pressure lettering. The fixed set procedure was used, and memory sets of two, three, and four letters were shown to each subject on index cards and well learned. The order of running the three blocks of memory set sizes was counterbalanced across subjects. The target letter was drawn from the memory set (requiring a "positive" response) or not (requiring a "negative" response) with equal frequency;

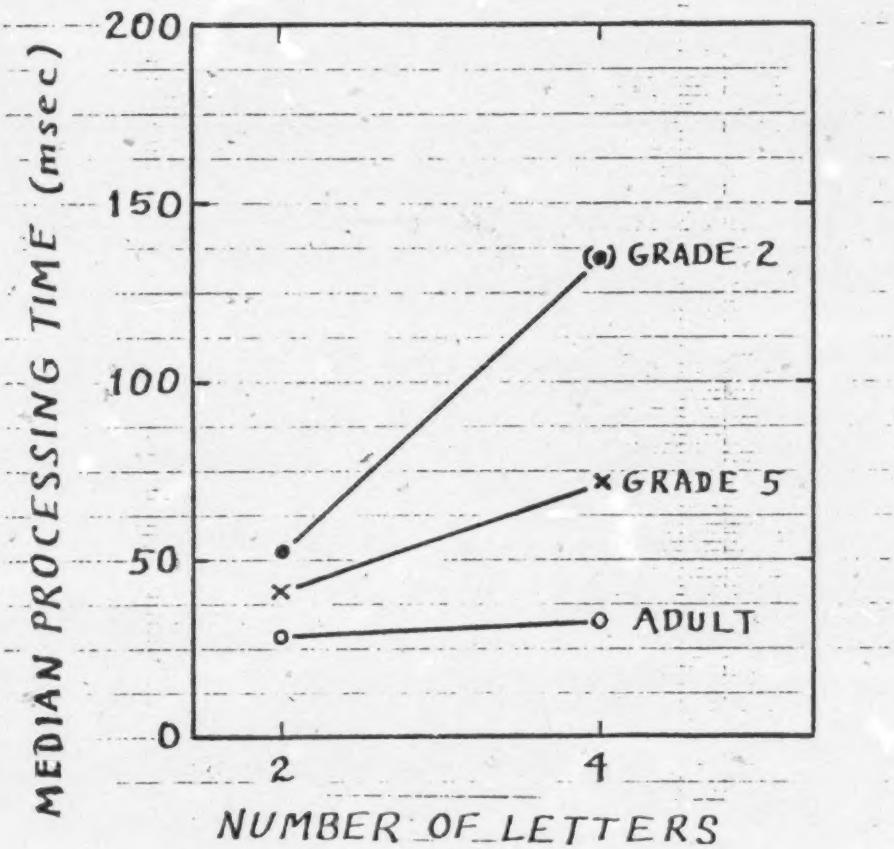

200
150
100
50
0
MEDIAN PROCESSING TIME (msec)
(•) GRADE 2
× GRADE 5
o ADULT
2
4
NUMBER OF LETTERS

FIGURE 6

it was shown in a Scientific Prototype two-field tachistoscope (model 800F, viewing distance, 80.5 cm.; background luminance, 69 cd/m^2). There were 24 target presentations per memory set size per subject, twelve "positive" and twelve "negative". Subjects responded by pushing a three-position toggle switch up for positive responses and down for negative responses. Moving the switch terminated the target display. Median reaction time was calculated for each subject for each condition. Erroneous responses were discarded; analysis of variance of error frequency showed that the Age x Set Size interaction was not significant.

Figure 7 gives the outcome in terms of means of the subjects' median scores. The average slope of the least squares regression lines did decrease with age (see the values on the Figure), but analysis of variance[7] showed that the differences were far from significant. This absence of significant age differences confirms the earlier studies.

Figure 8 allows us to view the literature's developmental findings in the context of many of the adult studies (taken from Cavanagh's, 1972, review). The various stimulus materials are shown on the abscissa. The vertical bars depict the range of memory scanning rates reported in adult studies, and the x's are the means of the adult studies. The short horizontal lines are the rates reported in the developmental studies.[8] For digits, letters, and drawings, the age differences in rate are obviously minimal relative to the range of adult rates. In general, moreover, the children's rates are neither slower nor faster than the bulk of the adult rates. However, the rate differences for Gibson forms[9] are considerable, though not significant. We remain puzzled by the developmental data.

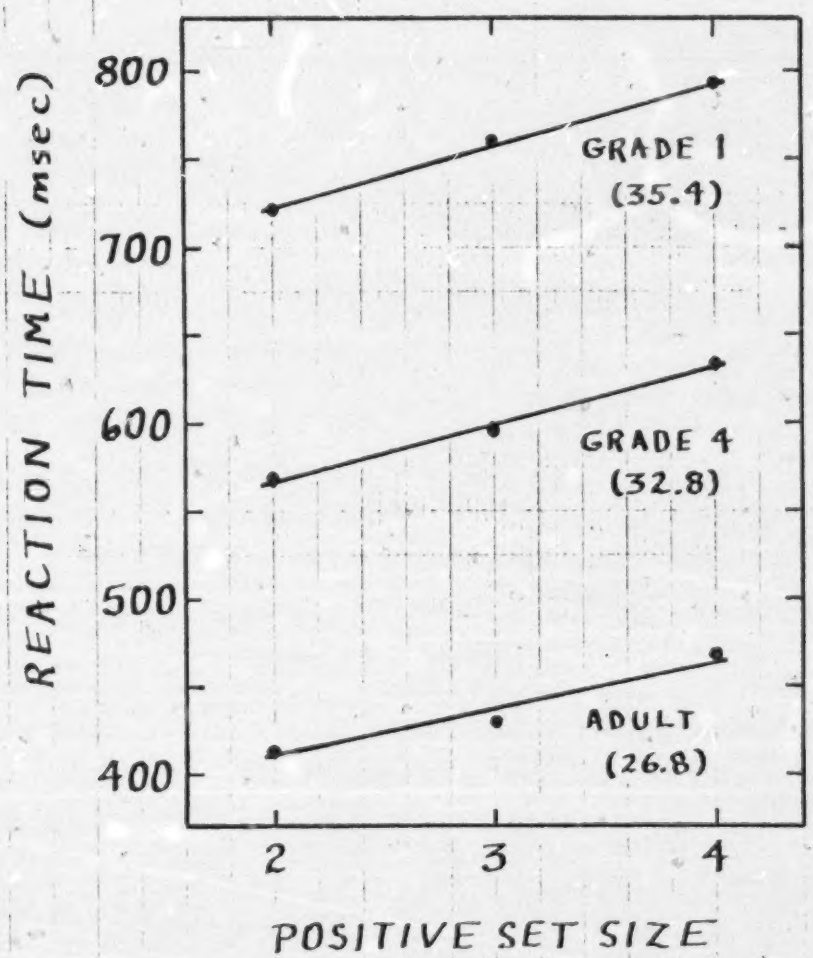

REACTION TIME (msec)
800
700
600
500
400
GRADE 1
(35.4)
GRADE 4
(32.8)
ADULT
(26.8)
2
3
4
POSITIVE SET SIZE

FIGURE 7

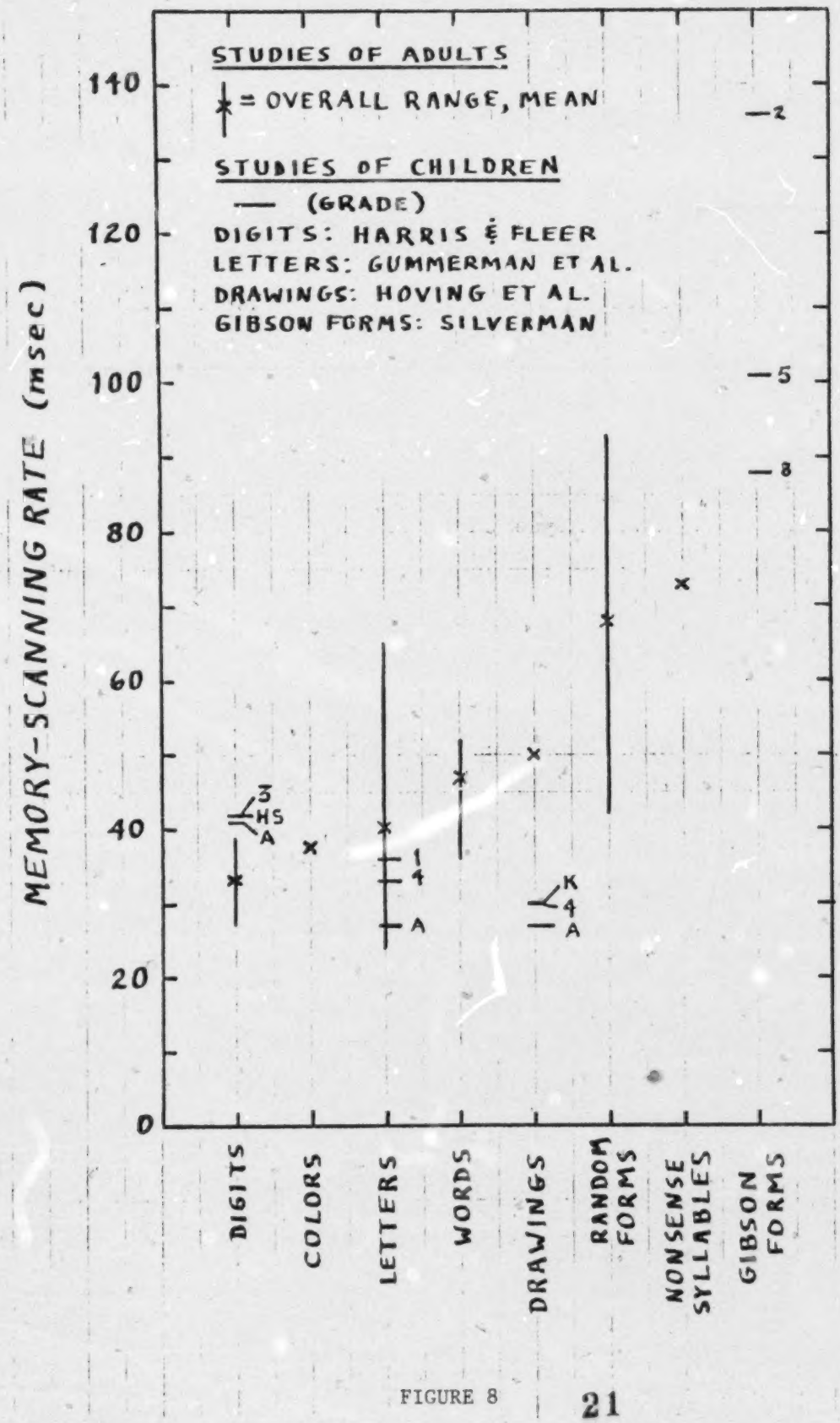

STUDIES OF ADULTS
= OVERALL RANGE, MEAN
STUDIES OF CHILDREN
(GRADE)
DIGITS: HARRIS & FLEER
LETTERS: GUMMERMAN ET AL.
DRAWINGS: HOVING ET AL.
GIBSON FORMS: SILVERMAN
MEMORY-SCANNING RATE (msec)
140
120
100
80
60
40
20
0
2
5
8
3
HS
A
1
4
A
K
4
A
DIGITS
COLORS
LETTERS
WORDS
DRAWINGS
RANDOM FORMS
NONSENSE SYLLABLES
GIBSON FORMS

FIGURE 8

NOTES

1. This work was supported by grant HD07614 from the National Institute of Child Health and Human Development.

2. We are extremely grateful to the subjects, their parents, and to Dr. and Mrs. Ned Roy of the Running R Day Camp of Austin, Texas.

3. We wish to express our appreciation to the second- and fifth-graders, their parents, and to the principal, faculty, and staff of the Eanes Elementary School in Westlake Hills, Texas.

4. A simplifying assumption that is obviously not correct since it predicts no serial position effects. The assumption may be altered without affecting the model when serial position effects are to be considered.

5. One variation is serial processing with a variable starting point. Another is serial processing with variable and independent processing times for each item. (We are grateful to Philip B. Gough for the latter suggestion.)

6. We again wish to thank the children, their parents, and the principal, faculty, and staff of the Eanes Elementary School in Westlake Hills, Texas.

7. For this statistical analysis, two regression lines were calculated for each subject's median reaction times, one for positive responses and one for negative responses. These slopes were the scores for the analysis. No main effect or interaction was significant.

8. The numerals refer to grade levels. "K" denotes kindergarten, "HS" is high school, and "A" is adult.

9. Silverman's (1974) article did not express data in terms of rates. We calculated them from the table of reaction times provided.

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